Energy Beyond LHC
Tough Question #2

We do not know how to create superconducting (accelerator) magnets at industrial scale with fields above about 16 T. Is any solution on the horizon?

M. Lamm

Slightly reframe the question

We would like to know if accelerator magnet technology will be timely for proposed future accelerators or accelerator upgrades (circa 2030)

On what time scale would we be able to build 16-20 T accelerator magnets on an industrial scale?

Time to Bring a Magnet Concept to Industrialization

Based on experience with prototyping new accelerator magnets and industrial experience from LHC the following sequence is suggested: (with approximate durations in red)

Step 1) A solid preliminary design based on proven technologies time depends on incremental change from previous state of the art.

Step 2) Time to built short model (final design, tooling, some R&D still required) 3 years

Step 3) Time to extend to full scale prototypes (some R&D required for scale up) 2 years

Step 4) Time to do technology transfer to industry 5 years but can overlap with step 3

Step 5) Start fabrication stage on industrial scale.. i.e. ~8-10 years past "step 1"

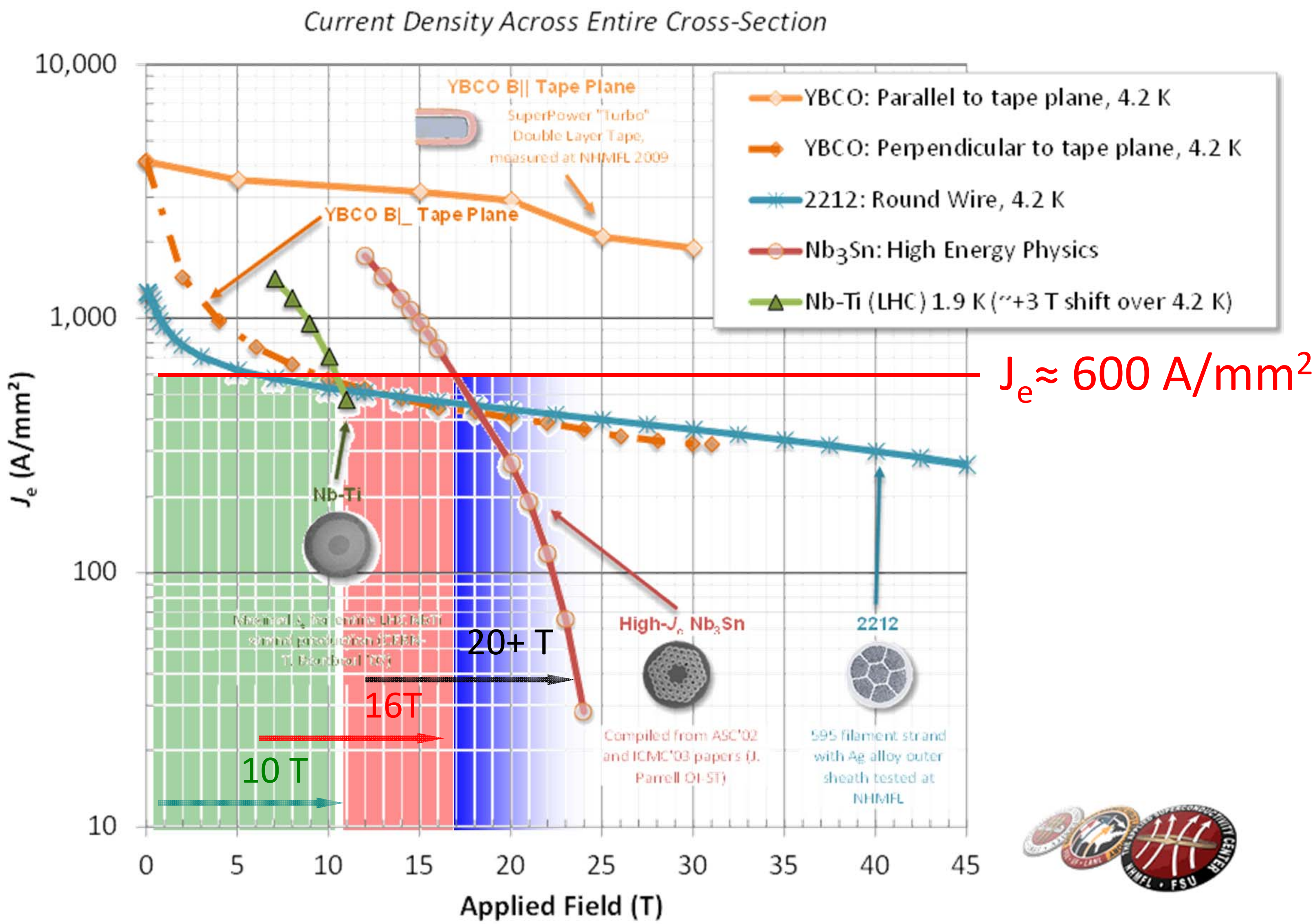
State of high field accelerator magnet technology

- After ~10 years of intense R&D, primarily at the US DOE national labs, we can reliably build accelerator quality Nb_3Sn dipoles and quads with operating peak fields on conductor of ~12 T
  - Advances in Nb3Sn conductor, high Jc at 12 T, smaller filament diameters to largely minimize conductor instabilities and magnetization effects at low fields, good field quality
  - Reliable coil technologies to safely handle brittle Nb3Sn, coils up to 3.5m have been successfully built (size limited to oven and test facilities)
  - Mechanical structures to handle high large magnetic forces without damaging coils
- Advanced plans to install Nb_3Sn magnet in LHC with the next 5-10 years
  - 11 T cosine (θ) dipoles by 2018 (in select locations in LHC lattice)
  - High gradient cosine (2θ) quads by ~2023 (IR Quad upgrades, 20 magnets)
  - These magnets will likely be made at the US national labs, CERN and/or European Industry
  - CERN has already started conversation with European Industry

State of high field accelerator magnet Industrialization

- **No Nb_3Sn accelerator magnets have yet been industrialized, however**
- **Many companies in the world, in Europe, Asia and North America have capabilities to fabricate industrial scale magnets including Nb3Sn**
  - Companies or offshoots of companies that made magnets for LHC
  - Nb3Sn ITER magnets
  - Other NbTi projects
- **US DOE laboratories have industrial capabilities for small of medium size projects**
  - ½ of the LHC IR quads were made at Fermilab, all cryostated at Fermilab.
  - Pre-industrialization strategies can be proven here

Status of Superconductors



Data compilation and graphics by courtesy of P. Lee (ASC-NHMFL) via Luca Bottura (CERN)

What these next generation magnets would look like?

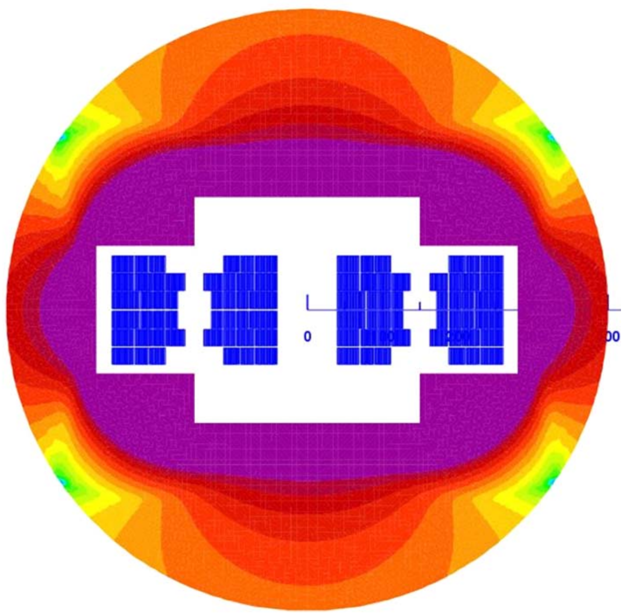
15-16 T

Possibly made of Nb_3Sn only (on the limit of what is possible because you have to operate at ~80% short sample), large conductor volume to compensate for low Jc. Complex mechanical structure to accommodate large Lorentz forces. Possibly need to go away from traditional "cos(θ)". Since forces go like ~B^2 and Jc is falling rapidly, 15 T magnet would be much easier than 16 T…

20 T

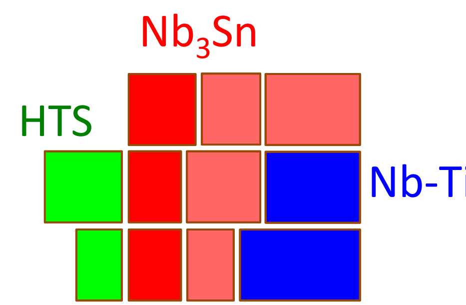
Hybrid magnet, with combinations of NbTi, Nb3Sn and High Temperature Superconductor (HTS) materials. Coils are no longer traditional "cos(θ)" Again, complex mechanical structure to accommodate large Lorentz forces. **Big departure from existing accelerator magnets.**

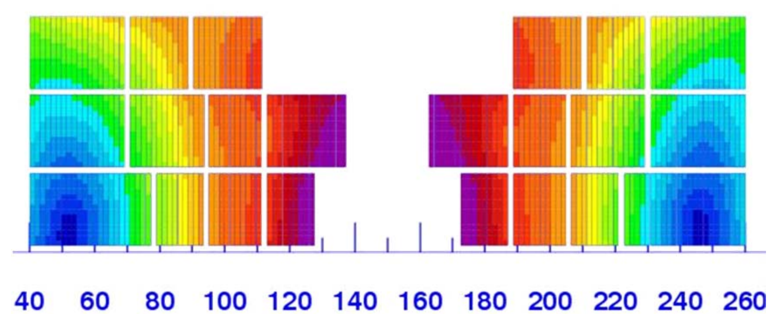
One Example for 20 T Concept



A 20 T HE-LHC dipole

E. Todesco, L. Rossi (CERN)





- Block design
- Graded winding
- Stress management built into coil (not shown)

So where are we with high field accelerator magnets?

- **Short term goal for magnet community is to get the HL-LHC (~12T) "industrialized"**
- **Estimate 3-5 years of effort would be required to complete "step 1 preliminary design" for 15-16 T all Nb3Sn dipole (i.e. 13-15 years from now to start build in industry)**
  - Build on progress from HL-LHC /LARP program
  - High field magnet R&D at LBNL, Fermilab and in Europe
  - 15 T would be a lot easier than 16 T magnet
- **Estimate 10 years of effort to complete "step 1" for a 20 T hybrid dipole (i.e. 20 years from now to start build in industry)**
  - Large departure from existing industrialized technology
  - Need additional progress with HTS conductor and coil fabrication
- **These estimates assume funding and effort comparable to the present LARP magnet program on these specific magnets**

With a concerted effort, ~15-16T magnets could conceivably be fabricated in industry for an energy upgrade starting in 2030 (but not much earlier)

If 2030 is the goal for installation, we need to make technology decision by 2020.